IEEE Southcon/90 Conference Record, Vol. 1, pp. 60-63, 1990

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DESIGN AND USE OF A BAROREFLEX TESTING DEVICE

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INTRODUCTION

The ability to test the carotid baroreceptors is a relatively recent innovation. Physiologists had long been interested in accurately determining the responsiveness of these receptors located in the neck which rapidly adjust heart rate to control blood pressure response. NASA studies have now determined that the baroreceptor response is adversely affected by exposure to microgravity and to earth-bound 0-g simulation studies. This attenuated response can cause problems with orthostatic tolerance upon return from space flight, an undesireable effect especially in the landing scenario. To study this reflex response a system was developed to rapidly and accurately stimulate the carotid baroreceptors. A description of this system is the subject of this paper.

METHODS

NASA life scientists decided approximately 6 years ago that a study should be conducted on a Shuttle Spacelab mission to examine the effect of microgravity on the baroreflex response. Preliminary work in this area had been accomplished by Dr. Dwain Eckberg who experimented with a number of neck chambers (2). The early units were made of lead and fitted only a narrow range of subjects. The Engineering Development Laboratory (EDL), an independent design group, was selected to design and build a flight system that would enable the investigators to apply positive and negative pressures via a neck chamber and measure heart rate changes due to application of this pressure (3). The flight system designed is now ready to fly aboard both the SLS-1 Spacelab and the German D-2 Spacelab. EDL went one step further in designing a much less expensive commercial unit that was actually more versitile than the flight unit. One of these early units was obtained by this laboratory and was the subject of a number of modifications to make it more responsive to needs of our investigators. This modified system will now be described.

SYSTEM DESCRIPTION

The heart of the system is a bellows that is driven by a stepper motor. This stepper motor derives its control from a programmable peripheral interface (PPI) chip which is resident on a custom board installed in an IBM microcomputer (or clone). Use of this concept and information about necessary interfaces is well documented in a text by Tompkins (4).

Software, originally written in basic, is now written and operating in C. This software addresses the PPI which has three controllable ports. Three subroutines continuously run in the software sampling trigger points from the electrocardiogram (ECG), respiration, and pressure. The desired pressure profile is programmed along with timing specified in the number of heartbeats per pressure stage. The appropriate commands are issued to control the stepper motor to obtain the desired pressure profile. The majority of testing to date

utilizes the Eckberg profile shown in Table 1.

Pressure (mmHg)	Number of heart beats
40 mm Hg	4
25 mm Hg	1
10 mm Hg	1
-5 mm Hg	1
-20 mm Hg	1
-35 mm Hg	1
-50 mm Hg	1
-65 mm Hg	1
0 mm Hg	1

Table 1 - Eckberg pressure profile

With a properly fitting neck chamber, the pressure waves measured at the neck are essentially square wave steps. The baroreceptors on the carotid arteries perceive the positive 40 mm Hg pressure as a rapid ambient change that makes effective blood pressure equal to the systolic pressure minus 40. Heart rate is then measured as the interval between beats (R-waves) and expressed in milliseconds. After a four beat baseline (at +40 mm Hg) is established, the pressure is rapidly stepped downward each heartbeat and is perceived by the carotid receptors to be an increase in blood pressure which causes heart rate to decrease (and consequently R-to-R interval to increase). It is critical to the system operation that the time interval between heart beats be accurately measured. This application relies on a 5 MHz crystal controlled clock resident on the custom board to obtain accurate timing. This provides better time resolution than normally available with the onboard PC clock.

The system in use in our laboratory uses a Lifepak 5 Monitor to acquire the raw ECG. This off-the-shelf unit is battery operated, provides superior patient protection, allows the selection of three different chest leads, and provides a CRT display of the signal. The Lifepak 5 output is fed to the custom card on which an ECG high pass filter and a buffer amplifier condition the signal for use by both an A/D converter and a Schmidtt trigger.

The pressure signal is derived from a transducer close to the bellows which itself is closely coupled to the neck chamber. The pressure signal conditioning is carried out on the custom board with the signal being fed to the second A/D converter. Provisions are also provided in the pneumatics to quickly dump the pressure if selected positive or negative limits are reached or if the test is manually aborted by the test conductor.

It is important to stabilize the subject's respiration during the stepping protocol. Normally, respiration causes a person's heart rate to go up during inspiration and decrease during exhalation. To eliminate this effect, the subject's respiration is monitored by a thermister held close to a nostril. After two normal breaths, the subject is instructed to stop breathing at mid expiration. The bellows then applies the +40 mm Hg pressure to the neck so that the baseline can be established. The respiration signal is also buffered and applied to the third A/D converter.

A block diagram is shown in Figure 1 to assist the understanding of this basic concept. All three A/D's feed the bus and the PPI performs the control under

software direction. The 5 MHz clock feeds an 8253 timer which is accessed by software to obtain accurate timing of R-to-R interval.

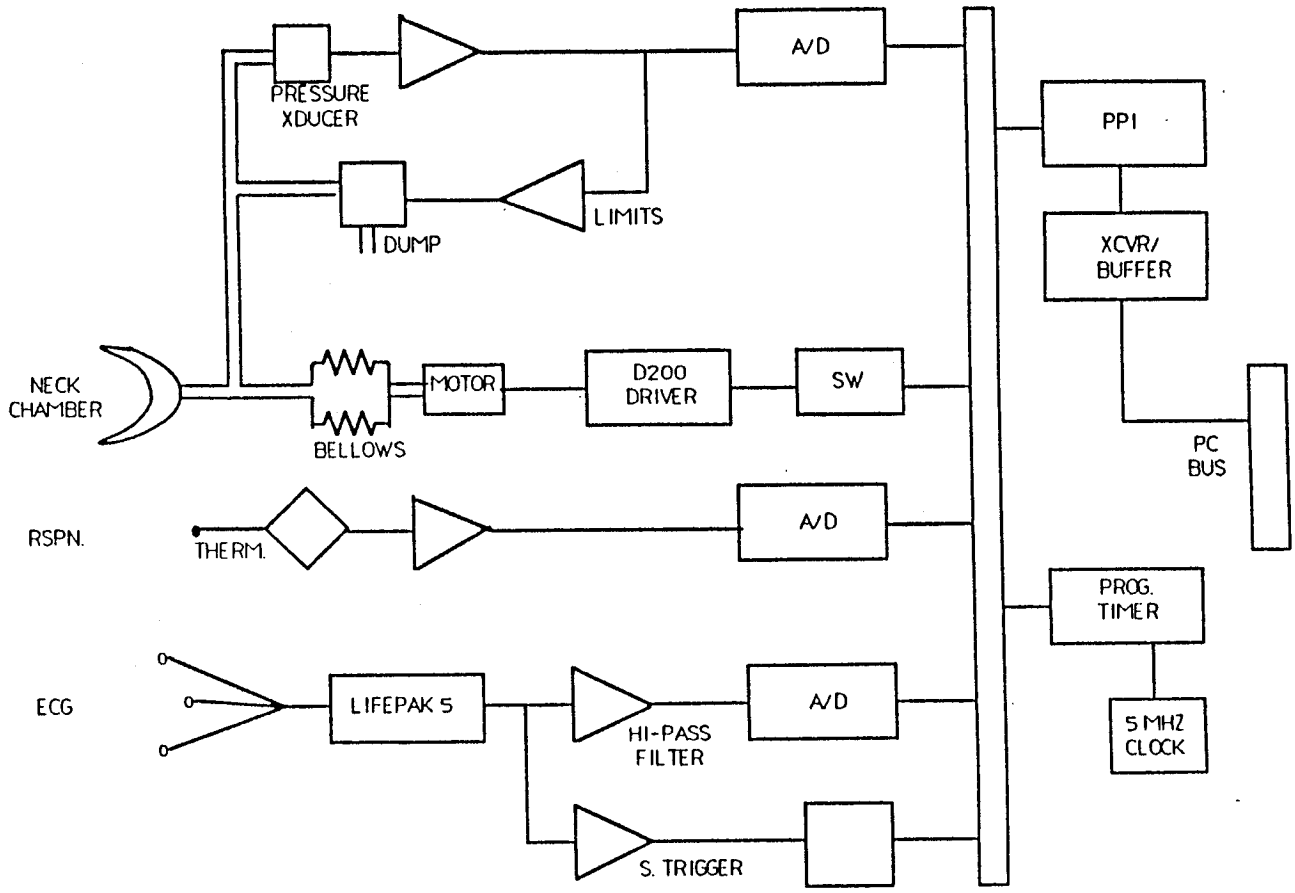

Figure 1 - Block diagram of Baroreflex system

The C-software program was written in-house to include many features not available with the original basic program. This program allows either the standard Eckberg profile or creation and use of a virtually limitless selection of custom profiles. The normal test session runs the profile seven times and then creates session averages. However, this software allows any number of profiles to be performed because running average data is kept on file. Data can be reviewed each run and even plotted to the CRT with a single keystroke.

The data file structure stores raw data, session averages, and subject data. Format of files is arranged so that easy transfer to a speadsheet, such as Symphony, is accomodated via an ascii file. Other calculations such as R-to-R maximum and minimum intervals and slope are calculated realtime.

Enhanced color graphics displaying the respiration, pressure waveform, and electrocardiogram are presented during the testing. Pull down menus are incorporated to make the software easier for physiologists or other medically oriented personnel to employ all software features.

RESULTS

The system described has been used by this laboratory for a number of studies including a 30 day bedrest study conducted at the NASA Ames Research Center in California (1), a 24 hour circadian monitoring study at KSC, a 10 week training study, and a quadraplegics study at the Lucerne Hospital in Orlando. A study was also conducted to examine the repeatablity of the measurement using the same subject at the same time of day a week apart and also ten weeks apart. Data from the one week repeatability study showed that the five primary variables considered, namely R-to-R interval, minimum R-to-R, maximum R-to-R, slope, and R-to-R range did not differ pre-test to post-test with a $P < 0.05$. The correlation coefficients ranged from 0.85 to 0.91 at the $P < 0.0001$ level of confidence.

Another important conclusion derived from use of this modified instrument was that it was reliable. A wide variety of subjects were tested successfully, sometimes on occasions where system failure would mean complete loss of data from the study, ie. the bedrest study where day 28 data can only be obtained on that day or else repeat the entire protocol.

CONCLUSION

The basic concept of this design was originated by the Engineering Design Laboratory in Newport News, VA. Special needs of this laboratory required that a number of modifications be accomplished to make the unit suitable for our investigators. The resulting system has been reliable and offers highly repeatable data. It is user friendly and is now responsive to a wide variety of subject parameters which would ordinarily make them difficult, if not impossible to test. While the unit can be operated on a variety of computers, no machine changeouts are made during a study in this laboratory to preclude subtleties in the software from creating undetected measurement errors or causing improper system operation to occur. Future efforts will be directed toward the fabrication of a more compact unit that will likely install a clone motherboard directly into the current enclosure along with the features of the Lifepak 5 ECG monitor.

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